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THE OHIO STATE UNIVERSITY ELECTROSCIENCE LABORATORY
RADAR/RADIOMETER FACILITIES FOR PRECIPITATION MEASUREMENTS

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TECHNICAL REPORT 2374-13

March 1973

Grant Number NGR 36-008-080

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National Aeronautics and Space Administration
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NOTICES

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ABSTRACT

The OSU ElectroScience Laboratory Radar/Radiometer Facilities are described. This instrumentation includes a High-Resolution Radar/Radiometer System, a fully automated Low-Resolution Radar System, and a small Surveillance Radar System. The High-Resolution Radar/Radiometer system operates at 3, 9, and 15 GHz using two 9.1 m and one 4.6 m parabolic antennas, respectively. The Low-Resolution and Surveillance Radars operate at 9 and 15 GHz, respectively. Both the High- and Low-Resolution systems are interfaced to real-time digital processing and recording systems.

This capability was developed for the measurement of the temporal and spatial characteristics of precipitation in conjunction with millimeter wavelength propagation studies utilizing the Advanced Technology Satellites. The precipitation characteristics derived from these measurements could also be of direct benefit in such diverse areas as: the atmospheric sciences, meteorology, water resources, flood control and warning, severe storm warning, agricultural crop studies, and urban and regional planning.

CONTENTS

I. INTRODUCTION

The OSU ElectroScience Laboratory Radar/Radiometer Facilities were developed in 1972 to provide a basic, yet versatile, capability for the measurement of the temporal and spatial characteristics of precipitation. Both fine scale and gross characteristics of precipitation and, in particular, intense thunderstorm cells are required in the prediction of attenuation statistics on earth-space communication links operating at millimeter wavelengths. These data are also required for the determination of the optimum spacing, orientation, and reliability improvement of such links operating in a space diversity mode and for the analysis of interference effects due to precipitation scatter. Furthermore, a detailed knowledge of such a common natural process is of value throughout a wide range of areas of interest such as: the atmospheric sciences, meteorology, water resources, flood control and warning, severe storm warning, agricultural crop studies, and urban and regional planning.

In the case of the millimeter wavelength earth-space attenuation problem one must know the instantaneous rain rate along the propagation path in order to predict the path attenuation. Since the propagation path is elevated this implies a knowledge of the rain rate as a function of both horizontal and vertical position. In addition, if one wishes to predict the reliability of such a link it becomes necessary to determine not only the statistics of the rain rate at an isolated point but also the joint statistics of the rain rate at the various spatially separated points along the propagation path.

In the case of the diversity problem one must know the rain rate and attenuation statistics enumerated above and, also, the joint statistics of these parameters as a function of the spatial path separation. This implies a knowledge of the gross characteristics of the precipitation such as storm cell size, shape and orientation as well as the fine scale structure of the precipitation within the cell.

The precipitation scatter interference problem requires essentially the same knowledge as that required in the attenuation problem. However, in this case one must be concerned with the attenuation incurred along both the incident and bistatic scattering paths.

Unfortunately, the rain rate information requirements stated above are not sufficient for the precise determination of attenuation and scattering effects in precipitation. The use of rain rate as a parameter descriptive of the precipitation process is only a convenient simplification. In reality, the phenomena of attenuation and scattering are directly dependent upon the precipitation particle size distribution which is not uniquely described by the rain rate. In addition, the precipitation particle shape, orientation, and state, i.e., liquid or solid, are also significant parameters in the determination of scattering and attenuation effects.

A third physical process, in addition to scattering and attenuation, which is associated with precipitation is that of noise emission. The noise emission throughout the microwave and longer wavelength portion of the millimeter wavelength spectrum is dominated by the contribution due to liquid water when precipitation is present; therefore radiometric temperature measurements may be related directly to the integrated liquid water content along a propagation path through a region of precipitation. For this reason radiometric temperature measurements have been found to be an extremely valuable adjunct tool, particularly in the case of attenuation measurements.

Thus it is evident that there are three categories of information required in the study of precipitation effects. They are:

1) precipitation particle characteristics (drop state, shape, orientation, and size distribution),

2) both gross and fine scale cell characteristics (cell size, shape, and orientation and precipitation distribution within the cell), and

3) relationships between rain rate, attenuation, scatter, and emission.

The facilities described in this report have been developed expressly for the purpose of obtaining empirical data of the nature described above. In view of the complex nature of the problem a versatile, comprehensive measurement capability was desired; nevertheless, system simplicity was sought in order to achieve a high degree of operational reliability and to ease the problems of data interpretation. With these objectives in mind, the instrumentation required for multi-frequency radar backscatter and radiometric temperature measurements was implemented. The measurements provided by this instrumentation, in conjunction with attenuation measurements on earth-space links when an appropriate satellite is available, will provide a comprehensive set of attenuating scatter and noise emission data.

Section II of this report presents a brief description of the major elements of the various radar and radiometer systems; this summary is intended to provide the reader with an overall view of the capabilities of these various systems. Section III contains the specifications of those elements common to several of the systems and includes a tabulation of all the significant system parameters for the purpose of comparison. The remaining sections detail the specifications of the high and low resolution systems. The detailed description of the digital data processing portions of the systems will be presented in succeeding reports and, therefore, is not included in this document.

II. GENERAL DESCRIPTION

This radar/radiometer instrumentation system is located at the ElectroScience Laboratory's Satellite Communication Facility, shown in Fig. 1, 1320 Kinnear Road, Columbus, Ohio (lat. 40^{o} 00' 10" N, long. 83^{o} 02' 30" W). Figure 2 shows the relative locations of the various antennas located at this facility; and a general block diagram of the system to be described in this report is presented in Fig. 3.

The High Resolution Radar/Radiometer System (HI-RES System) utilizes three of the existing five large aperture parabolic antennas at this facility. The HI-RES System consists of a radar/radiometer pair at each of three frequencies in the S, X, and Ku bands. Each radar/radiometer pair shares an aperture; the S- and X-band pairs using the West and South 9.1 meter antennas, respectively, and the Ku-band pair using the 4.6 meter antenna (see Fig. 2). The three antennas may be controlled independently or they may be slaved and slewed together so that they are looking along parallel paths. The radars are conventional magnetron pulse radars, and the radiometers are of the Dicke type. The three radars and three radiometers are interlaced such that the three radars fire sequentially in time. When a given radar is firing, the radiometer sharing that aperture is switched to the reference load resulting in greater isolation between the radiometer and radar. The radar backscatter is digitally integrated over a series of successive radar pulses on a range bin-by-range bin basis; and then both the radar backscatter and radiometric temperature data are recorded on digital magnetic tape. Additional data such as time, azimuth angle, elevation angle, and transmitted power are recorded on the same digital magnetic tape. The digital integration, formatting, and recording are all performed in real time. The radar backscatter data is also displayed on an A-scope and may be photographed if desired. This system provides the capability for scanning single or multiple cells in either azimuth or elevation and recording the radar backscatter with a resolution typically on the order of 200 meters and the radiometric temperature with angular resolution on the order of 0.3^{o} simultaneously at S, X, and Ku-bands.

The Low Resolution Radar System (LO-RES system) is a fully automated system designed for 24 hour/day, unmanned data acquisition. This system utilizes a conventional 9 GHz commercial marine pulse radar and 0.7 m parabolic antenna. The antenna rotates continuously in azimuth with a fixed elevation angle. Every five minutes the radar video signal is sampled and digitally integrated over one complete antenna rotation. If the integrated backscatter is larger than a preset threshold level, the successive scan is digitized and recorded on magnetic tape. The date, time, azimuth angles, and transmitted power levels are also recorded on this magnetic tape. The radar data may also be displayed on a conventional 360^{o} PPI display with a maximum range of 100 Km. This system provides the capability for gathering statistical data concerning size, intensity, shape, orientation, and movement of thunderstorm cells continuously over long periods of time.

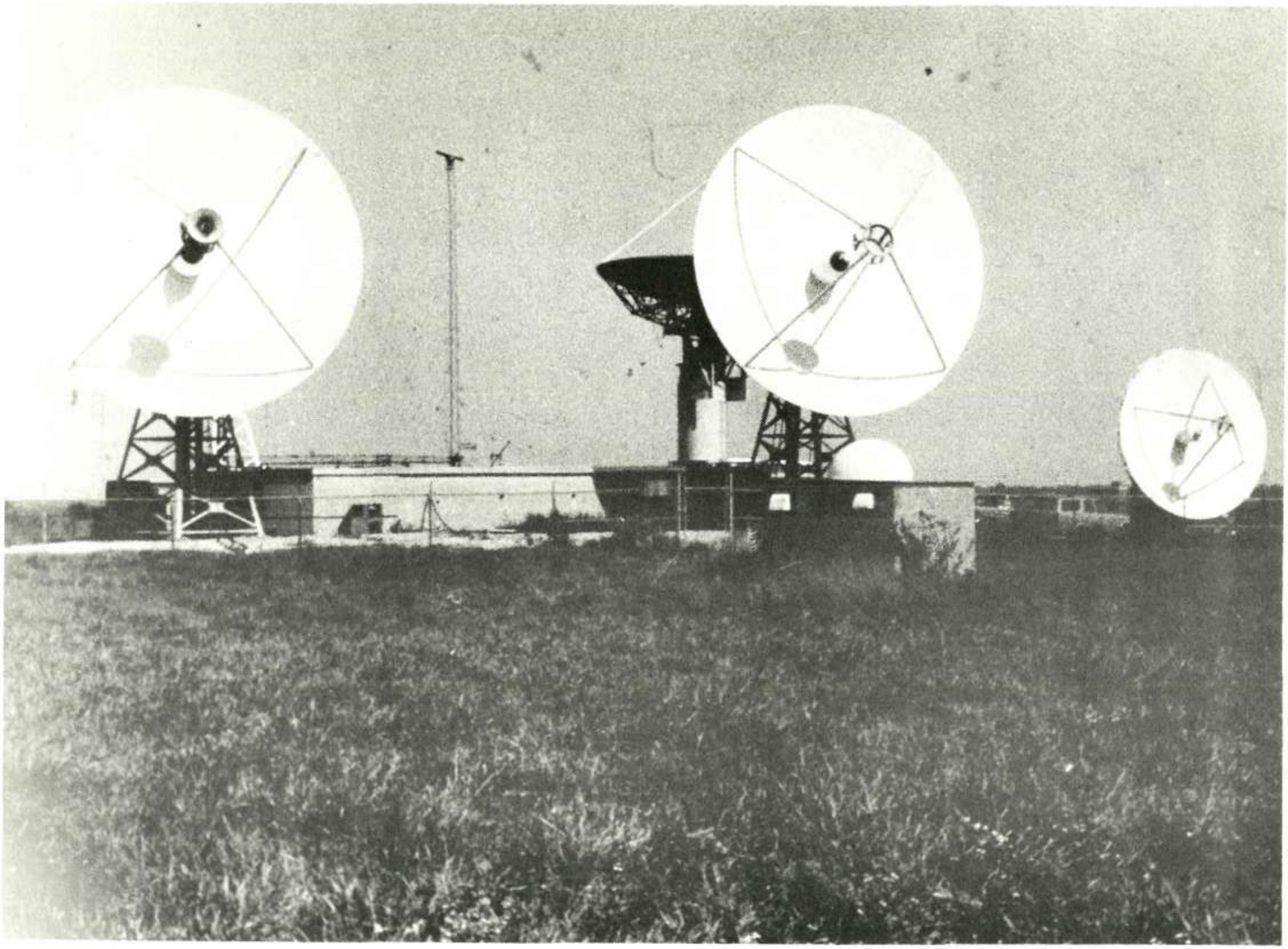

Fig. 1. OSU ElectroScience Laboratory Radar/Radiometer Facilities.

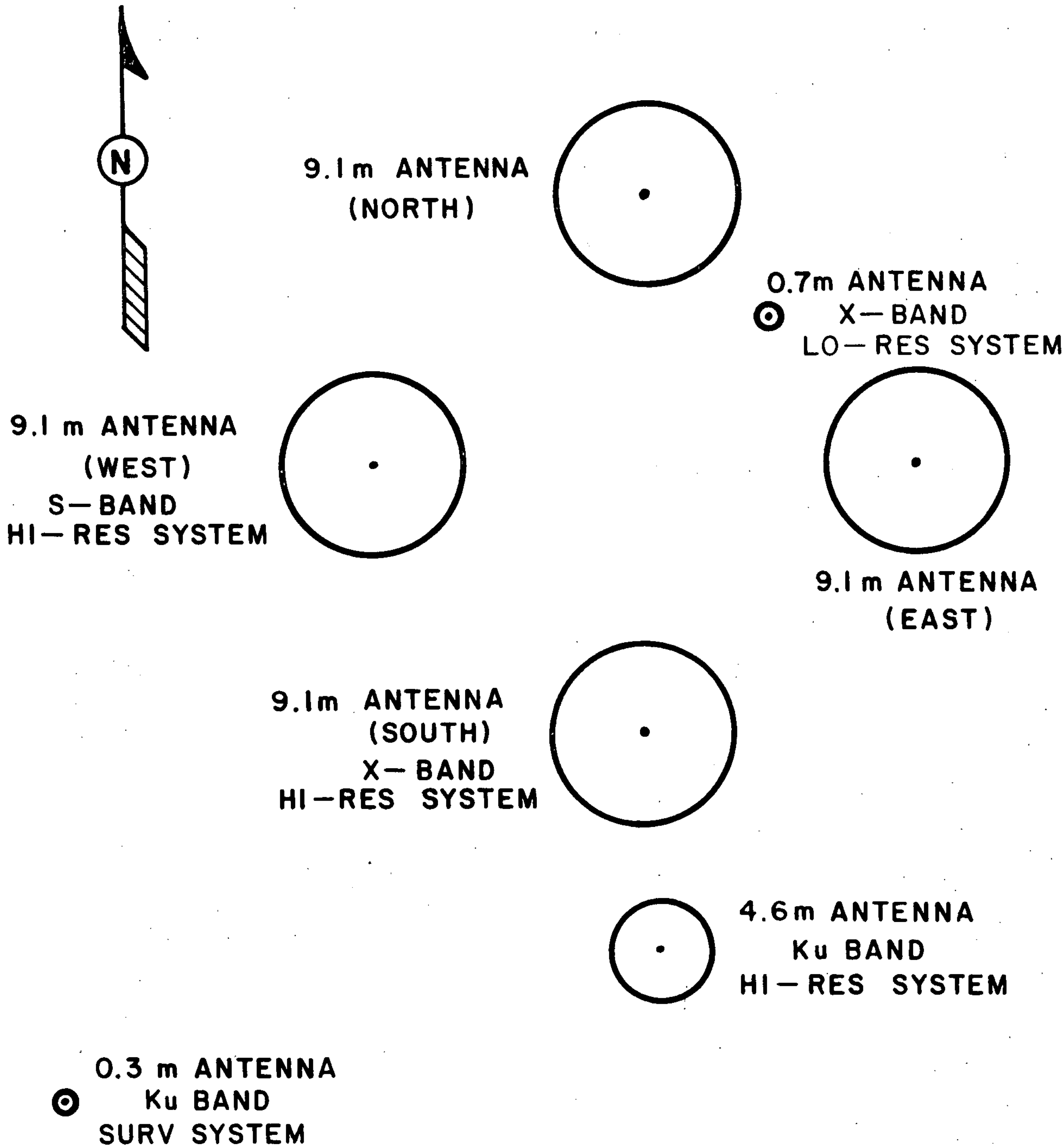

Fig. 2. Antenna locations.

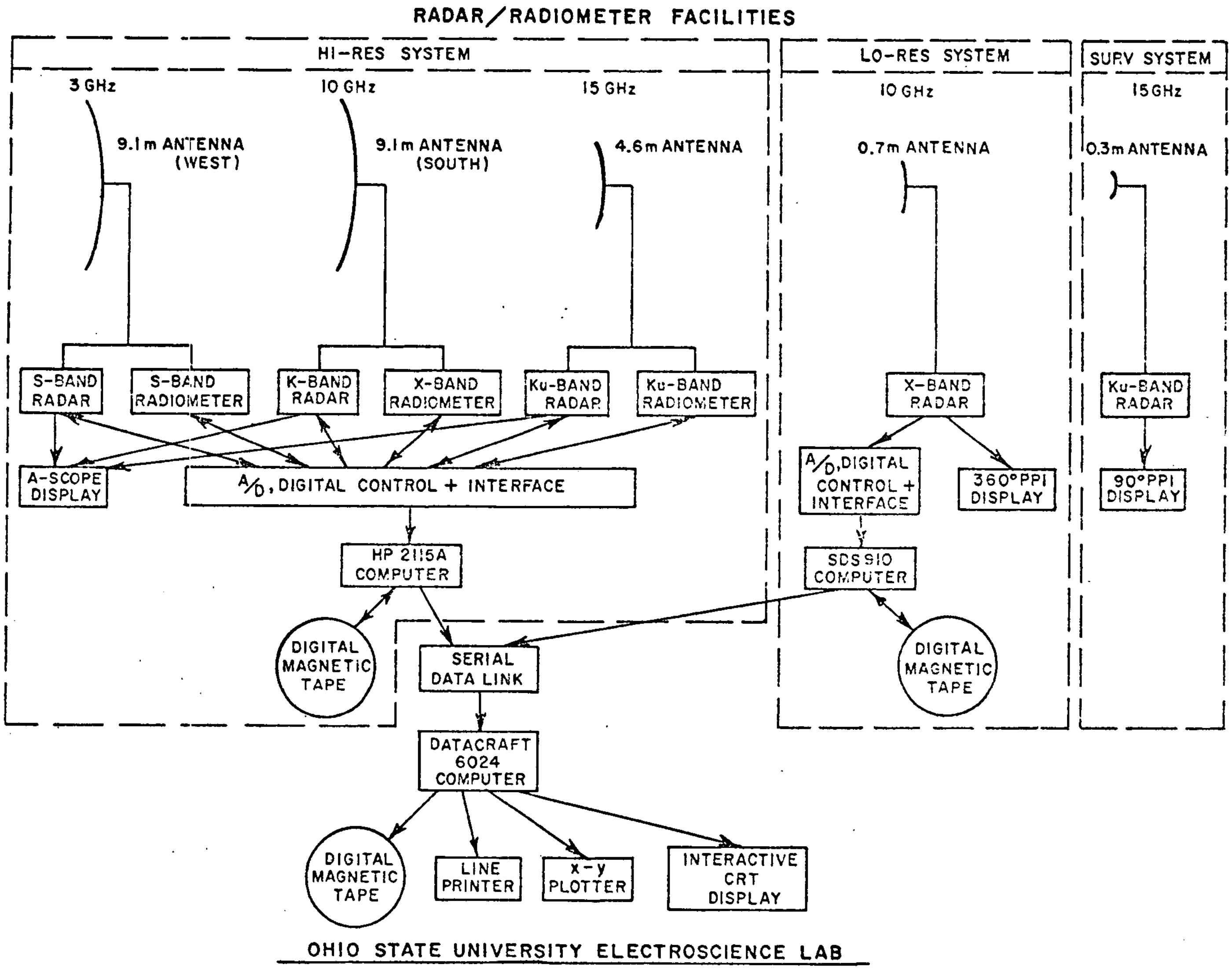

Fig. 3. Block diagram of Radar/Radiometer Facilities.

The Surveillance Radar System (SURV System) is a small aperture (0.3 m) conventional 15 GHz commercial aircraft weather avoidance pulse radar. The antenna mount provides a 90° azimuth sector scan which is completely steerable in azimuth and elevation. The radar video is presented on a 90° PPI display with a maximum range of either 12 or 60 km. This system and the LO-RES system provide surveillance capabilities yielding information about the locations and relative intensities of cells which may be useful in determining the regions to be scanned by the HI-RES System.

The digital data tapes generated by both the HI-RES and LO-RES Systems may be transferred to the ElectroScience Laboratory's Signal and Data Processing facility via a direct data link at the convenience of the experimenter. Here the data may be placed in core, on magnetic dish, or on magnetic tape for further processing in either a batch or time-share mode. The peripheral equipment available for output includes: a line-printer, an X-Y plotter, and an interactive light-pen CRT display. The interactive light-pen CRT display is of particular value in reconstructing PPI displays and in performing on-line control of the digital data processing.

The North and East 9.1 meter antennas in the Satellite Communication Facility array are currently being used in conjunction with other experimental investigations at the Laboratory; nevertheless they represent major hardware items which might potentially be available for future precipitation studies. Additional Laboratory instrumentation of interest includes a fully transportable 4.6 meter parabolic antenna and equipment van shown in Fig. 4. This equipment was used as a diversity terminal in the ATS-5 satellite 15.3 GHz attenuation measurement effort and is designated for further attenuation measurements at 20 and 30 GHz when the ATS-F satellite becomes available. The potential of this instrumentation for bistatic radar or other remotely located measurements should, however, be noted.

III. GENERAL SPECIFICATIONS

The relative positions of the various antennas at this location are shown in Fig. 5. The building housing the associated instrumentation is located within the perimeter of the four 9.1 m antenna and is situated partially below grade in order to reduce the aperture blockage of the four antennas.

The characteristics of the various antennas are presented in Table 1. The transportable 4.6 m antenna has been included in this table for reference. The unblocked azimuth angle ranges listed in this table refer to those angles over which the apertures are completed unblocked at zero degree elevation; therefore, the antennas are generally usable over a considerably wider range with minimal blockage. The three antennas used in the HI-RES system have common, open fields of view over an azimuth range from 150° to 300°.

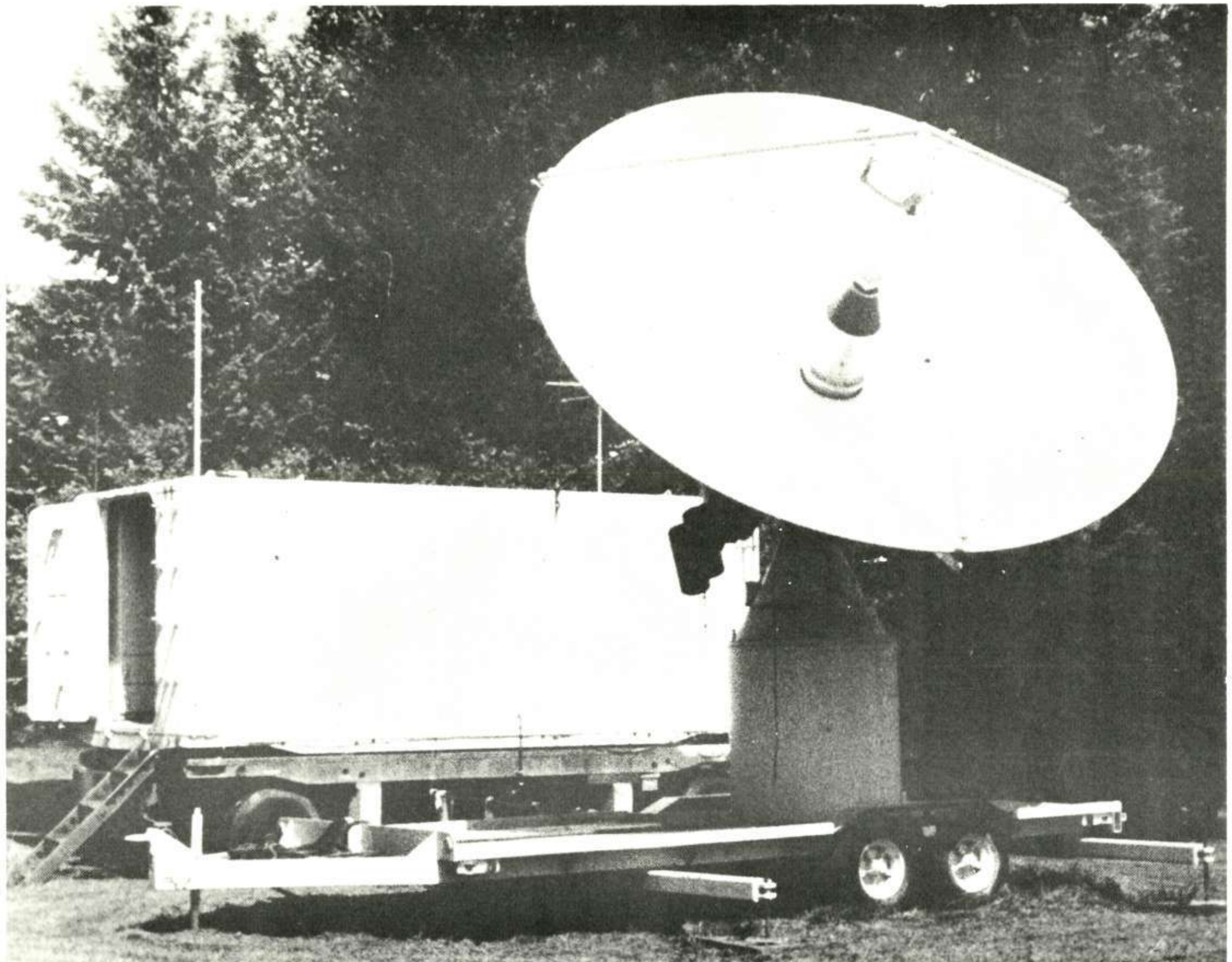

Fig. 4. Transportable antenna and equipment van.

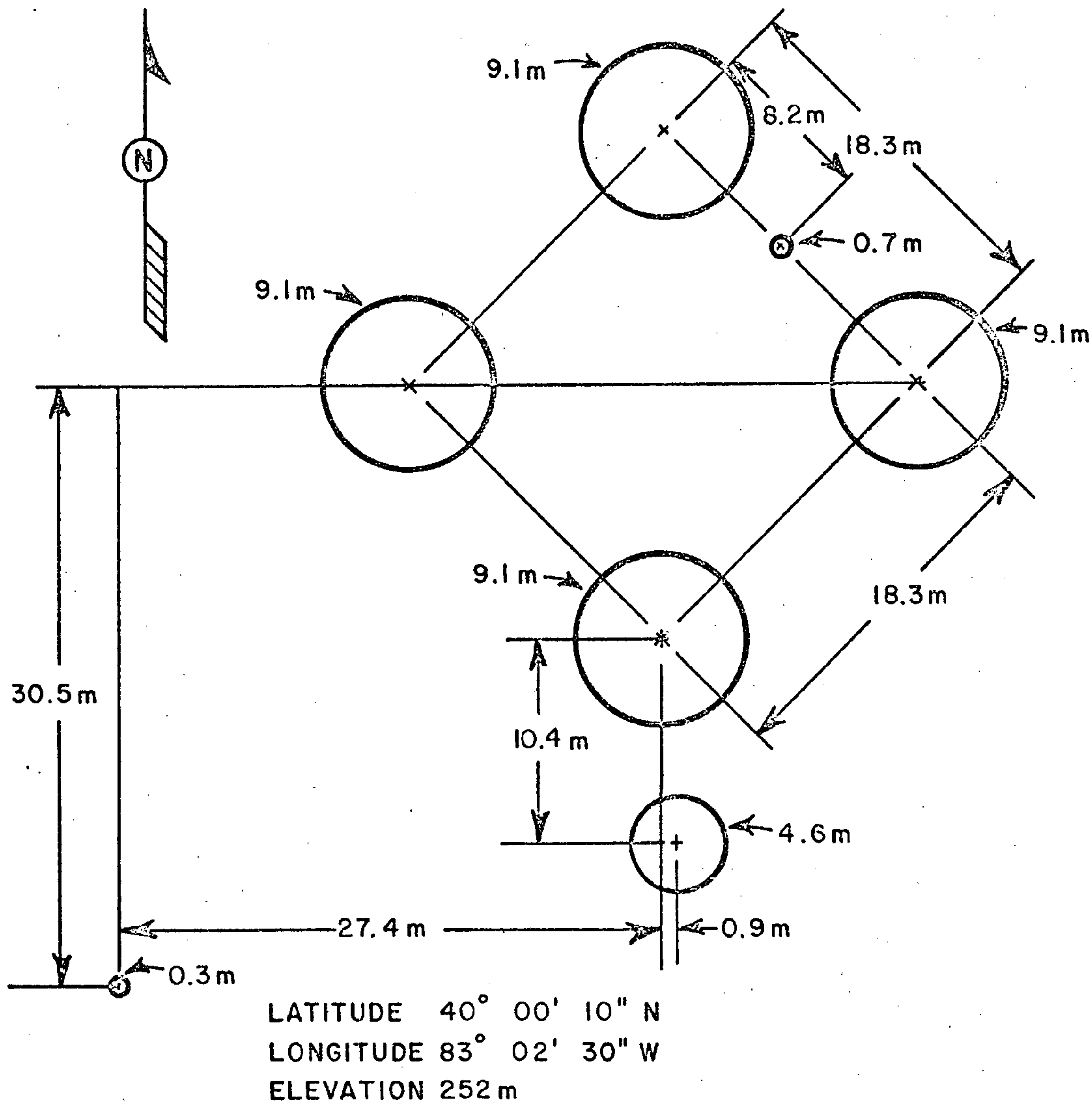

Fig. 5. Antenna site plan.

Tables 2 and 3 contain the radar and radiometer parameters, respectively.

TABLE 1
ANTENNA PARAMETERS

		Antenna Diameter (m)	Beam Width (deg.)	Minimum Elevation (deg.)	Unblocked Azimuth (deg.)	Polarization	Polarization Control	Azimuth Slew Rate (deg/sec)	Antenna Gain (dB)	Surface Tolerance (mm)	F/D
HI-RES	S	9.1	0.75	3.0	50 - 300	V	manual	0.3-1.0	46	1.90	0.416
	X	9.1	0.26	3.0	150 - 40	V	manual	0.3-1.0	56	1.90	0.416
	Ku	4.6	0.29	5.5	30 - 300	V	servo	0.3-1.0	54	0.64	0.48
LO-RES	X	0.7	3.5	0	0 - 360	H	fixed	12 or 144	27	2.00	0.42
SURV	Ku	0.3	4.4	5.0	75 - 15	V	manual	10 - 45	30	0.50	0.46
TRANS	Ku	4.6	0.29	0	-	-	servo	0.1-1.0	54	1.14	0.40

TABLE 2
RADAR PARAMETERS

		Frequency (GHz)	Wavelength (cm)	Peak Power (Kw)	Pulse Length (μs)	Repetition Rate (Hz)	Threshold (dBm)	Noise Figure (dB)	Bandwidth (MHz)	Sampling Interval (ms)	Number of Samples Integrated
HI-RES	S	3.050	9.84	20.0	1.0	100	-99	6.1	10	10	32
	X	9.348	3.21	25.0	1.0	100	-98	7.1	10	10	32
	Ku	15.560	1.93	7.9	1.6	100	-100	11.5	2	10	32
LO-RES	X	9.458	3.17	18.6	0.58	800	-96.5	10.3	5	5	32
SURV	Ku	15.560	1.93	7.9	1.6	800	-100	11.5	2	-	-

			Resolution Cell at 40 Km	
		Display	Diameter (m)	Length (m)
HI-RES	S	A-scope	524	150
	X	A-scope	182	150
	Ku	A-scope	202	240
LO-RES	X	360^{o} PPI	2,444	87
SURV	Ku	90^{o} PPI	3,073	240

TABLE 3
RADIOMETER PARAMETERS

		Frequency (GHz)	Bandwidth (MHz)	Integration Time (sec.)	Bits/Sample	Dicke Switching Rate (KHz)
HI-RES	S	3.30	20	0.1-1.0	8	1.6
	X	8.50	12	0.1-1.0	8	1.6
	Ku	15.10	20	0.1-1.0	8	1.6

IV. HIGH RESOLUTION RADAR/RADIOMETER SYSTEM

The switching of the HI-RES radars and radiometers are interlaced in time as shown in Fig. 6. Each radar is fired while its companion radiometer is switched to its reference load. The sequential firing of the three radars allows them to share a common A/D and integrator. After each radar fires the output of its IF is selected and the video is sampled at a 500 KHz rate. This sampling is initiated after a preset delay following the firing of the radar. One hundred successive samples are then stored in the integrator shift register. When that radar fires again, the process is repeated with the new samples being added digitally to the previous samples on a range bin by range bin basis. This procedure is repeated until 32 samples in each range bin have been integrated. The integrated data are then transferred to the data buffer. Thus, in effect, the integrated radar return from a range window containing 100 adjacent range bins and having an adjustable initial range is obtained. Typical resolution cell sizes associated with this system are shown in Fig. 7.

Block diagrams of the X and S band radars and radiometers are shown in Fig. 8. The radars are conventional short pulse magnetron units, the modulators supplied by the Cober Electronics Corp. The circulators are used to isolate the inputs of the radar and radiometer in each case. The radiometer bandbass is shifted away from the radar frequency slightly and a band rejection filter is placed in the radiometer in order to achieve isolation on the order of 150 dB between the radar transmitter and the radiometer. The radiometers are conventional Dicke type radiometers. The waveguide switch ahead of the circulators permits the injection of either coherent or incoherent calibration signals into both the radiometer and radar receiver. The cross guide coupler ahead of the waveguide switch provides a means of monitoring the transmitted power level. The cross guide couplers and noise sources have been calibrated and are traceable to the NBS.

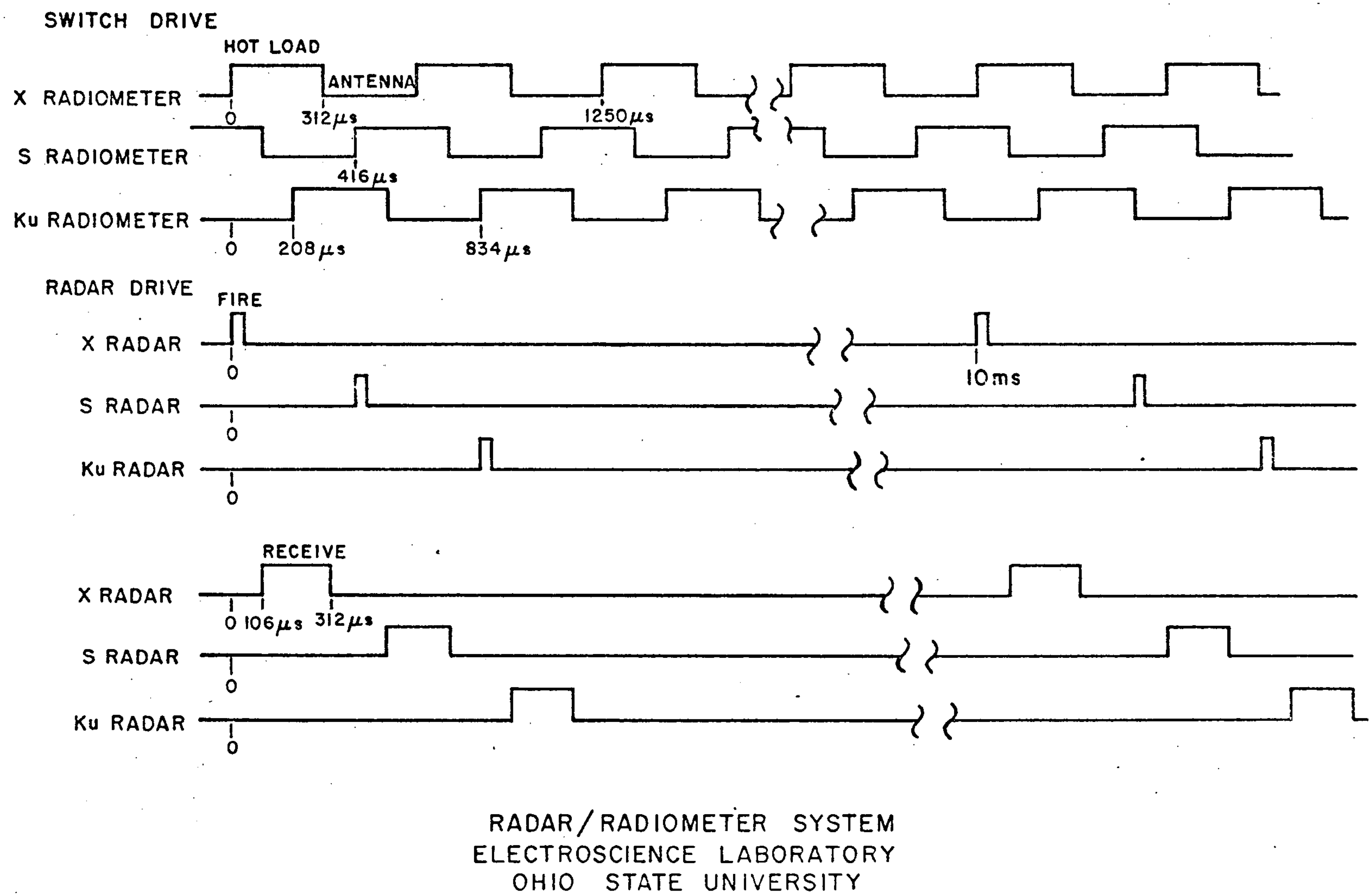

Fig. 6. HI-RES system interlacing.

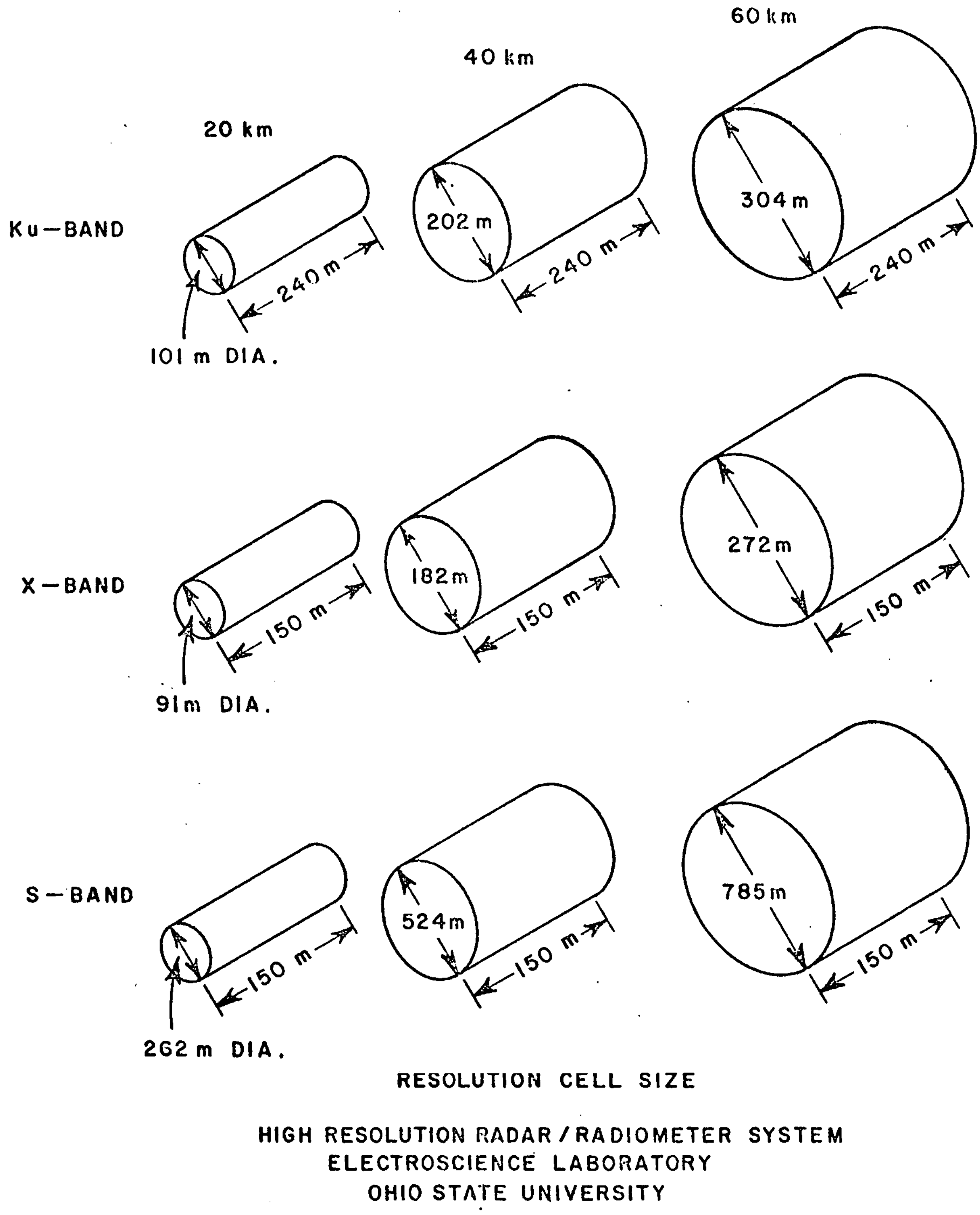

Fig. 7. Typical resolution cell sites.

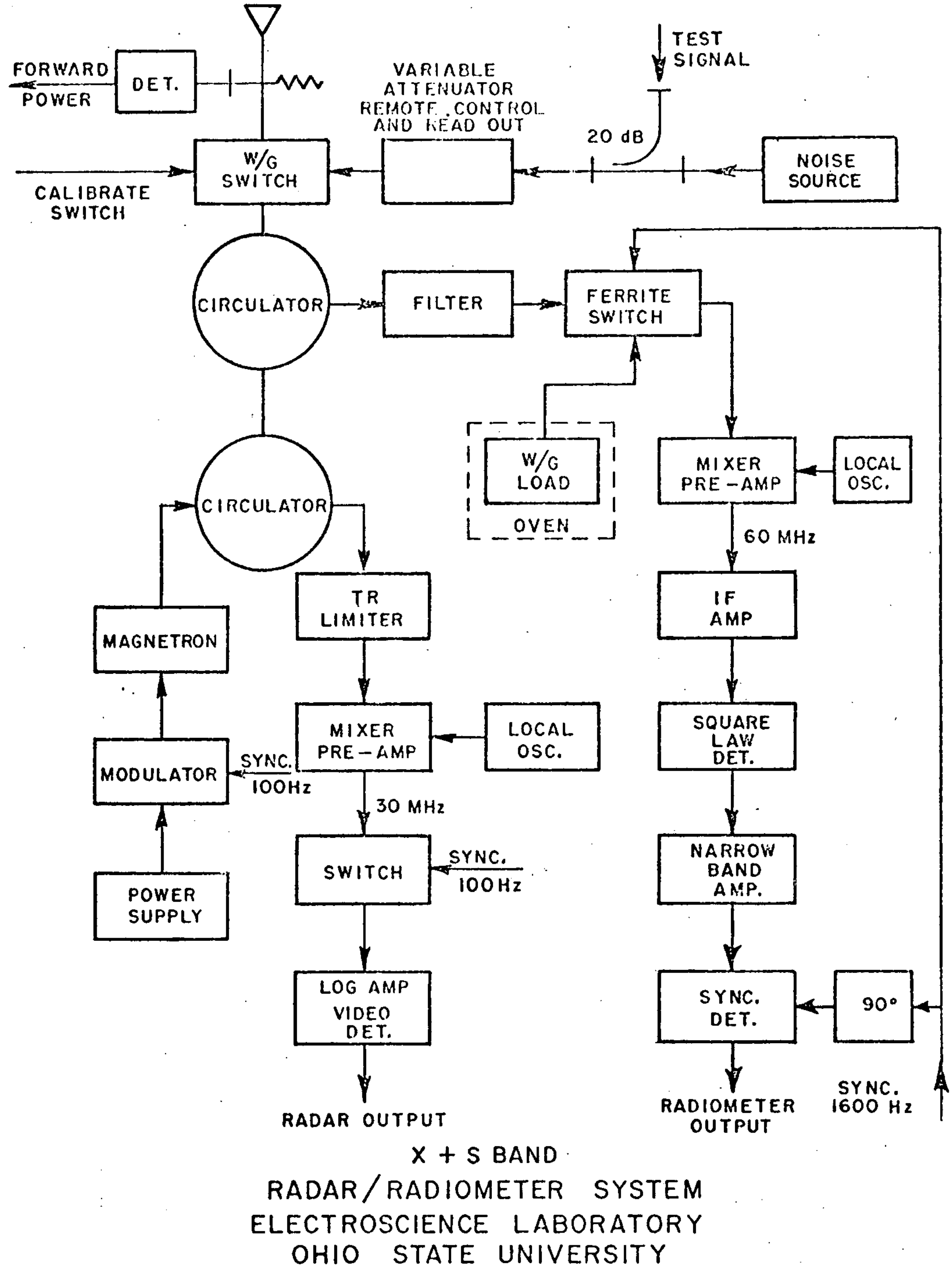

Fig. 8. HI-RES X and S band systems.

The block diagram of the Ku-band radar and radiometer is shown in Fig. 9. In this case a Bendix Weather Avoidance Radar was modified to provide the required radar capability; this necessitated a slight rearrangement of the cross guide coupler and waveguide switch for transmitted power monitoring and calibration signal injection. Otherwise, the S, X, and Ku band systems are essentially identical.

The outputs of each of the radars and radiometers are sampled and converted to digital form as shown in Fig. 10. The radar video signals are digitally integrated on a range bin by range bin basis as noted earlier. These data are then buffered, transferred to the HP-2115A computer, and stored on 7 track, 556 bpi magnetic tape. The data words recorded and their forms are tabulated in Table 4.

Under data taking conditions the antenna slew rate is preset, the initial antenna look angles are established, and data are then recorded as the antennas are slewed through the region of interest. This process is then repeated with any necessary adjustments in the slew rate or initial look angles. At any convenient point in time, calibration signals may be injected into the radiometers and radar receivers and recorded on the data tape.

V. LOW RESOLUTION RADAR SYSTEM

The LO-RES system utilizes an X-band Kelvin-Hughes marine radar modified to include a logarithmic IF amplifier. The system block diagram is shown in Fig. 11. This radar scans continuously in the horizontal plane. The radar video is sampled every 6 μs. to provide a range resolution of 0.78 km. Every five minutes the sampled video from an entire azimuth sweep is integrated and compared to a threshold level to determine if a significant target is present. If a target or targets are detected, the succeeding sweep containing 100 range bins at each azimuth angle is recorded automatically. The transmitted power and azimuth angles are also recorded on 7 track, 200 bpi magnetic tape as noted in Table 5.

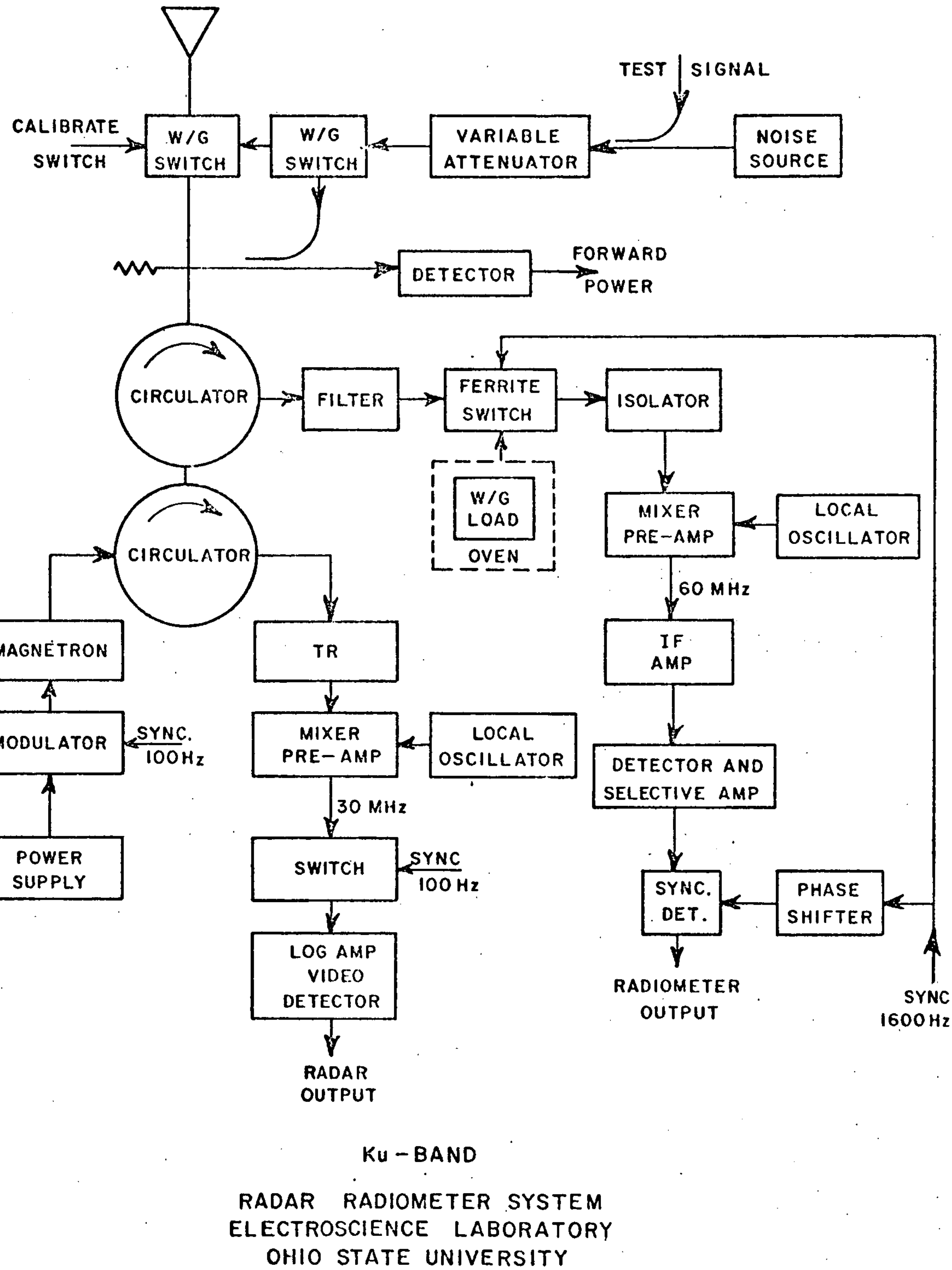

Fig. 9. HI-RES Ku band system.

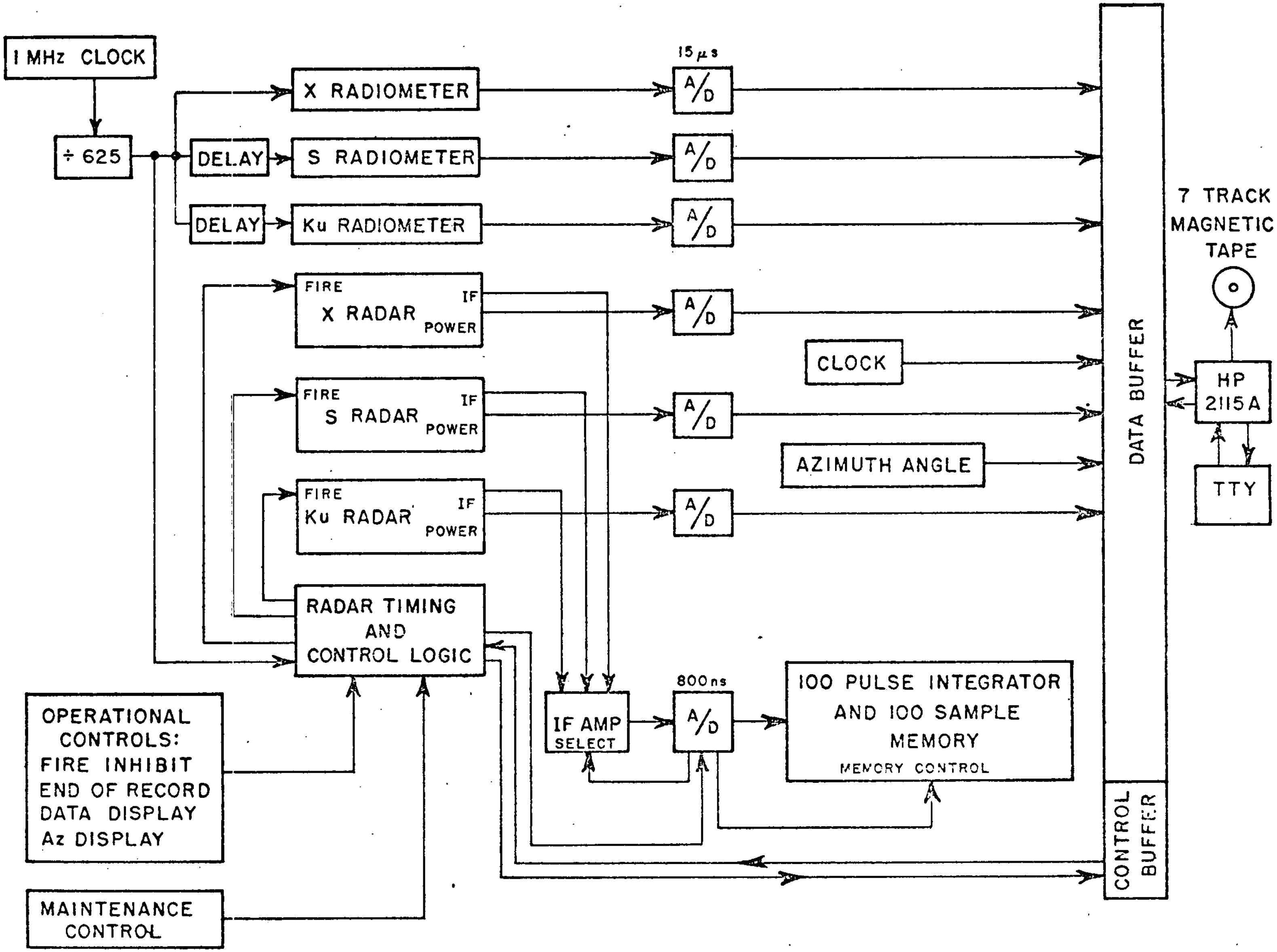

Fig. 10. HI-RES Radar/Radiometer system.

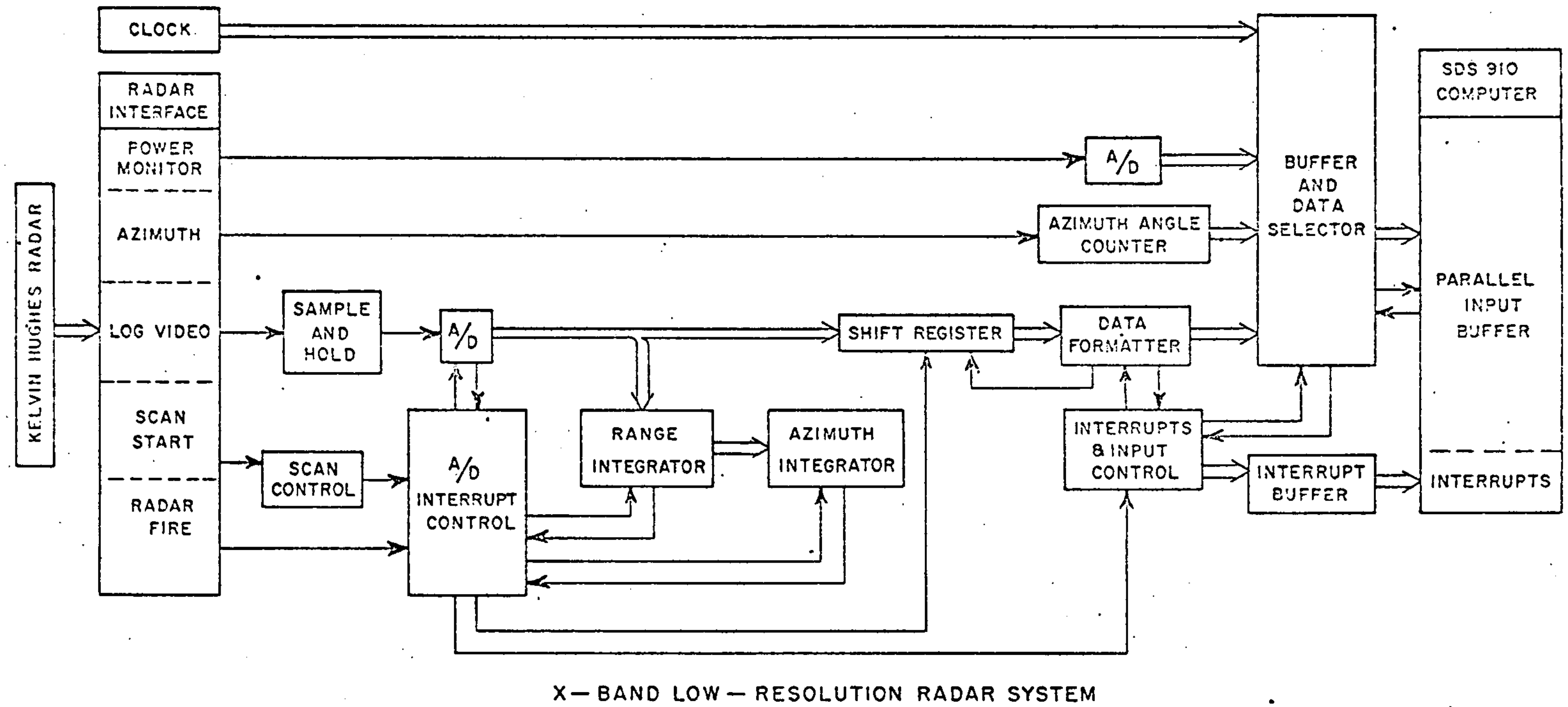

Fig. 11. LO-RES system.

TABLE 4
HI-RES DATA CHARACTERISTICS

DATA		16 bits/word
		312 words/azimuth angle
	CLOCK	3 words
	AZIMUTH ANGLE	2 words
	RADAR VIDEO	4 bits/range bin/frequency
		100 range bins/frequency
		3 frequencies
		300 words/azimuth angle
	RADIOMETER	8 bits/azimuth angle/frequency
		3 words/azimuth angle
	TRANSMITTED POWER	8 bits
	ELEVATION ANGLE	1 word
TAPE		
	SPEED	45 ips
	TRACKS	7
	DENSITY	556 bpi

TABLE 5
LO-RES DATA CHARACTERISTICS

DATA		24 bits/word
		15 words/angle
		57 azimuth angles/record
		5 records/azimuth scan
	CLOCK	24 bits
	AZIMUTH ANGLE	9 bits
	TRANSMITTED POWER	8 bits
	RADAR VIDEO	4 bits/range bin
		100 range bins
		13 words/azimuth angle
TAPE		
	SPEED	45 ips
	TRACKS	7
	DENSITY	200 bpi

VI. SUMMARY

The radar/radiometer systems available at the OSU ElectroScience Laboratory for precipitation measurements have been described. These facilities include high resolution S, X, and Ku band radar/radiometer systems for detailed three-dimensional mapping of thunderstorm cells and a low resolution, fully automated X band radar system for the collection of general thunderstorm cell shape and location statistics. These systems provide a capability of simultaneously measuring the radar backscatter and radiometric temperature associated with precipitation at frequencies in the S, X, and Ku bands. Both of these systems are interfaced to real time, digital preprocessing and recording systems.